

# **A Bio-economic Analysis of An Area Rotational Management Program in the US Atlantic Sea Scallop Fishery**

Demet Haksever, Deborah Hart and Stanley Wang\*

## **Sea Scallop Fishery and Management**

The Atlantic sea scallop resources are located on the continental shelf off the east coast of North America, from the shore of the Gulf of St. Lawrence, Canada, in the north to Cape Hatteras, North Carolina, USA in the south. Within the geographical range, a limited section to the US fishing industry spans from the Gulf of Maine to the Mid-Atlantic waters with scallop high density in George Bank, southern New England, and the mid-Atlantic ocean areas. These resources have been over-exploited based on the assessment of NMFS biologists (USDC 1998).

The U.S. sea scallop commercial fishery started along the Gulf of Maine coast in 1880's and expanded southward to the Mid-Atlantic region. In the 1990's, the U.S. landings of shucked sea scallops dropped steadily from the 1990 peak at 17,200mt to the 1998 low at 5,600mt, a drop of 67%. In 1994, fishing effort restrictions were imposed and in 1996, half of Georges Bank was closed to scalloping for protection of groundfish species (NEFMC 1993,1998). As a result of opening the half of Georges Bank for scalloping in 1999, the landings drastically increased to 10,100mt in 1999 from 5,600mt in 1998, an 80% increase.

The scallop landings have been highly concentrated, drawing from three major resource areas and landing in three states as shown in Chart 1. For example, in March 1998 - February 1999 fishing year, three resource areas contributed about three quarters (74%) of sea scallop landings: New York Bight (27%), Delmarva (24%) and Southern Channel (23%). Three states received more than 90% (92%) of the landings: Massachusetts (48%), Virginia (30%) and New Jersey (14%).

Dredging has been the predominant fishing method in the sea scallop fishery. For example, dredge vessels landed about 88% of the 1988 scallop landing with the balance of 12% caught by the other gears e.g., otter trawl gears. Most scallop dredge vessels are between 100 and 150 gross tons and participate in the fishery at different capacity (NEFMC 1993). Full-time scallop vessels generally fish year round and are distinguished from the other vessels in that they fish over 150 days at sea (DAS) and are also highly dependent on scallops for revenues. Part-time and occasional vessels fish for less than 150 DAS annually.

The U.S. federal government has managed the sea scallop resources in the U.S. exclusive economic zone since 1982. The first fishery management plan established and implemented a meat count standard of 40 shucked meats per

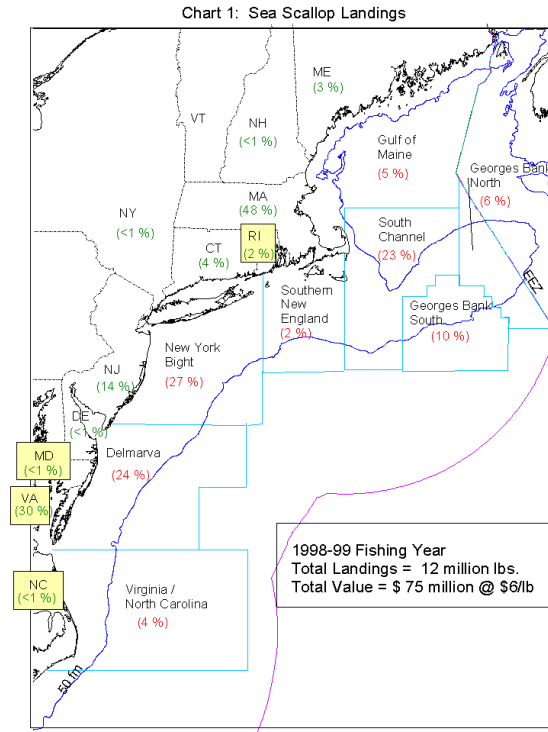
pound and a minimum shell height of 3.25 inches for scallops landed in shells in 1982 (NEFMC 1993, Wang et al 1986)<sup>1</sup> The management plan was amended several times and each amendment adjusted the meat count standard and its implementation procedures. Since 1994, a new management system consisting of a vessel permit moratorium and a vessel DAS control program has been implemented. The moratorium capped the number of permitted vessels while the DAS control program allocated a DAS quota per vessel and put in place an effort-reduction schedule reducing the DAS per vessel based on resource conditions.

Additionally, an area rotation management policy has been contemplated as a supplement to the existing system. The Scallop Plan Development Team of New England Fishery Management Council has been charged to develop area rotation management systems since 1999.

In this paper, a bio-economic simulation model for the sea scallop fishery is established and its application in analyzing the area rotation management policy is demonstrated. Section 2 describes model specification and estimation and presents the empirical model. Section 3 evaluates two policy options using the model and the last section provides a summary.

## **A Bio-economic Model**

The Bio-economic model consists of biological and economic components. The biological model is a size-structured model, which is an improved version of the model presented in the 1999 Scallop Stock Assessment and Fishery Evaluation Report (NEMFC 1999). The improvement includes an added stochastic simulation of recruitment, a finer spatial scale, an inclusion of non-landed fishing mortality terms, and an update of the initial conditions with National Marine Fisheries Service (NMFS) 1999 survey data. The population growth sub-model adopts a von Bertalanffy equation. The egg production is also tracked and based on the fecundity-shell-height relationship of MacDonald and Thompson (1985). However, the stochastic simulation of recruitment is not included in the paper.



### Biological Component.

(a). Population vector,  $p(i,t)$ :

$$p(i,t) = (p_1, p_2, p_3, \dots, p_j)$$

$p_j$  = the density of scallops in the  $j$ th size in area  $i$  at time  $t$ .

(b). Landing Vector,  $h(i,t_k)$ :

$$h(i,t_k) = [I - \exp(-\Delta t H(i,t_k))] p(i,t_k)$$

Catch at each size class in the  $i$ th region and  $t_k$  time step.

$I$  = identity matrix,

$H$  = diagonal matrix whose  $j$ th diagonal element,  $h_{ij}$ , is given below.

$$h_{jj} = \begin{cases} 0, & \text{if } S(j) \leq S_{\min} \\ -F(i,t_k)[S(j) - S_{\min}] / (S_{\text{full}} - S_{\min}), & \text{if } S_{\min} < S(j) < S_{\text{full}} \\ -F(i,t_k), & \text{if } S(j) \geq S_{\text{full}} \end{cases}$$

Here,  $S_{\min}$  is the minimum size at which a scallop is vulnerable to the gear,  $S_{\text{full}}$  is the size at which a scallop is fully vulnerable to the gear, and  $F(i,t_k)$  represents the fishing mortality rate suffered by a full recruit in area  $i$  at time  $t_k$ . Scallops of shell height less than a minimum size ( $S_d$ ) are assumed to be discarded, and suffer a discard mortality rate of  $d$ . There is also evidence that some

scallops not actually landed may suffer mortality due to incidental damage from the dredge. Caddy (1973) estimated that 15-20% of scallops remaining on the bottom after one pass of an offshore dredge were killed by such incidental damage. Using an estimated dredge efficiency of 40% (Rago et al 1999), this implies that  $0.09 = (1-0.4) \cdot (0.15)$  to 0.12 of the scallop originally on the bottom will suffer non-landed fishing mortality from one pass of the dredge. We therefore estimated that 10% of the scallop in the path of the dredge would be killed by incidental contact of the dredge. Again, using an estimated dredge efficiency of 40%, this implies that incidental mortality can be modeled as  $0.25F$ , where  $F$  is the landed fishing mortality rate of a fully recruited scallop. This incidental fishing mortality was applied equally to all size classes. Besides landed and incidental fishing mortality, scallops are also subject to natural mortality; this was established to occur at a constant rate for all size classes and areas, though in principle, it could depend on both size and location.

(c). Scallop von Bertalanffy equation

$S(t)$ , shell height at time  $t$ ,

$$S(t) = L_{\infty} [1 - \exp(-k[t - t_0])]$$

The growth equation is used to construct a matrix  $G$ , which specifies the fraction of each size class that remains in that size class, or grows to other size classes, in time  $t$ . Recruitment is modeled by assuming that new recruits enter the smaller size class (40-45mm in these simulations) at a rate,  $r_i$ , depending on the location  $i$ . Recruitment in each subarea was modeled to be consistent with the median historical patterns in that subarea (based on the period 1982-1999). The recruitment in each subarea was then proportionally adjusted so that the area weighted average recruitment was 99.9 for Georges Bank and 47.7 for the Mid-Atlantic, consistent with the methodology used in deriving Sustainable Fishery Act's target biomass levels. Recruitment for each stock subarea is assumed to equal the historical median because the empirical estimates of a stock-recruitment relationship were not statistically significant.

(d). Scallop Population Dynamics

$$p(i,t_k + 1) = r_i + G \exp(-\Delta t H) P(i,t_k),$$

where  $r_i = (r_i, \Delta t, 0, \dots)$ .

$G$  = Matrix specifying the fraction of each size growing to other size class in a time  $\Delta t$ .

(e). Shell-height meat-weight relationship

The following relationship is used to convert the population and landings in numbers by shell-height size class (S) into population biomass and landing weight (W).

$$W = \exp(a + b \ln s)$$

where W is the meat weight of a scallop of shell height s. For calculating biomass, the shell height of a size class was taken as its midpoint, while for purpose of calculating harvest biomass, it was taken as the midpoint of the size class after it has grown for half of a time step. The model also keeps track of egg production, based on the fecundity-shell-height relationship of MacDonald and Thompson (1985).

(f). Model Parameters and Verification.

A summary of the model parameters and area specific data are given in Tables 1-2. It should be noted that these parameters can be found in the reference cited above with some updates by Deborah Hart.

The entire biological model was verified using part of the historical data. The verification procedures were completed with (1) comparisons between observed and predicted landings per day at sea, (2) comparisons between observed and predicted survey indices, and comparisons between spatial distributions of fishing effort predicted by the model and observed in a vessel monitoring system. In the verification process, however, it was found that the model consistently over-predicted the landings. This

**Table 1: Model Parameters**

Parameter	Description	Value
$\Delta t$	Simulation time step	0.005 y
$L_{\infty}$	Maximum shell height	162 mm
$K$	Growth parameter	$0.3374 \text{ y}^{-1}$ (GB), $0.23 \text{ y}^{-1}$ (MA)
$M$	Natural mortality rate	$0.1 \text{ y}^{-1}$
$a$	Shell height/meat wt parameter	-11.4403 (GB), -12.3405 (MA)
$b$	Shell height/meat wt parameter	3.0734 (GB), 3.2754 (MA)
$S_o$	Initial shell height of recruit	40 mm
$S_{min}$	Minimum size retained by gear	65 mm
$S_{full}$	Size for full retention by gear	88 mm
$S_d$	Maximum size discarded	75 mm
$d$	Mortality of discards	0.2
$c$	Incidental fishing mortality	0.25F
	Dredge efficiency	0.4

**Table 2. Area and assumed recruitment for each management designation used in projections.**

Management designation	Area (nm <sup>2</sup> )	Recruitment
<b>Georges Bank</b>	<b>7,435</b>	Medium
South Channel	1,391	Medium
Southeast Part	1,593	Medium
Northern Edge and Peak	972	Medium
Closed Area I	636	Medium
Closed Area II-N*	867	Medium
Closed Area II-S*	965	Medium
Nantucket Lightship Area	1,010	Medium
<b>Mid-Atlantic</b>	<b>8,404</b>	Medium
New York Bight	5,342	Medium
Delmarva	1,403	Medium
Hudson Canyon Closed Area	1,466	Medium
VA/NC Closed Area	193	Medium

\*Closed Area II-N comprises that part of Closed Area II in survey strata 71,74,631,651, and 661; while Closed Area II-S is that part of Closed Area II in strata 59, 61 and 621.

discrepancy could be potentially due to several factors including unreported and/or undocumented landings. Therefore, in order to maintain the model consistency between the biological and economic components, the predicted catch of the biological model should be adjusted down proportionately to be equal to the observed landings used in the economic modeling. This adjustment starts with the initial year of the biological simulation and extends into future to facilitate an economic assessment as explained in a policy evaluation section later.

#### Economic Component:

The economic component includes an ex-vessel price equation, a cost function and a set of equations describing the consumer and producer surpluses. The ex-vessel price equation is used in the simulation of the ex-vessel prices, revenues and consumer surplus for the two policy options for a ten-year period. The cost function is used for projecting harvest costs and thereby for estimating the producer benefits as measured by the producer surplus. The set of equations also include the definition of the consumer surplus, producer surplus, net economic benefits and the estimation of present values for these variables.

##### (a). Ex-vessel price equation

The price of sea scallops at exvessel levels (PEX) is postulated to be a function of domestic landings (DLN), disposable income (DPI), average price of all scallop imports to the Northeast region (PIM), and average meat count (AMC). The postulated relation between PEX and each of explanatory variables is indicated with a sign next to each explanatory variable: A “-” sign indicating an inverse relation and a “+” sign, a direct relation.

$$PEX = f(-DLN, +DPI, +PIM, - AMC).$$

Other things being equal, higher landings would lead to a lower price. Higher income would result in a higher price because sea scallop is considered a normal good. Higher price of scallop imports as a substitute would lead to a higher price for domestic scallops as well. Normally, larger scallops command a higher price because they are preferred in restaurant markets. Since the size of scallops is measured in meat counts per pound, smaller meat count implies that the scallops are larger compared to a pound of scallops with a higher meat count. Therefore, smaller meat count representing larger scallops would be associated with a higher ex-vessel price, implying an inverse relation between average meat count (AMC) and the ex-vessel price (PEX).

In the empirical estimation, the price equation is assumed to take a semi-logarithm functional form and estimated with the ordinary least squares method using annual data for a period from 1982 through 1999, with the

exception of the year 1989 for which no meat count data were available. All the price variables are corrected with inflation and expressed in the 1997 constant prices by deflating the current prices with the consumer price index (CPI) for food. Disposable income is also expressed in the 1997 dollars by deflating nominal values with the GDP implicit deflator. The empirical ex-vessel price equation is presented below. Generally speaking, the empirical equation is consistent with the postulated relation and has proper statistical properties.

$$\begin{aligned} \text{Log (PEX)} = & 1.5587 - 1.06\text{E-}08 * \text{DLN} + 1.09\text{E-}05 * \text{DPI} \\ & (4.97) \quad (-5.40) \quad (1.11) \\ & + 0.1181 * \text{PIM} - 0.0103 * \text{AMC} \\ & (4.49) \quad (-2.67) \end{aligned}$$

n= 15, adj R-sq = 0.91, D-W = 1.80, t-value in parentheses.

##### (b). Operating cost equation

Fishery management measures not only affect the level of landings and prices of scallops, but also have an impact on the trip and operating cost of vessels. Since cost data are needed for estimating producer surplus and thus net national benefits (consumer and producer surpluses), specification and estimation of cost equations are necessary for analyzing policy options. The operating cost of scallop fishing (OPC) is postulated to be a function of vessel crew size (CREW), vessel size in gross tons (GRT) and vessel days at sea (DAS). As before, a ‘+’ sign indicates a directional relation and a ‘-’ sign, an inverse relation.

$$OPC = f(+ \text{Crew}, + \text{GRT}, + \text{DAS})$$

This cost equation was assumed to take a double-logarithm form and estimated with data collected by the Economic and Social Science Branch of Northeast Fisheries Science Center. The operating cost includes food, ice, water, fuel, gear, supplies and half of the annual repairs. The detailed information on the cost/earnings data are available in two studies: Gautam and Kitts (1996) and Edwards (1997). The empirical equation presented below verifies the postulated hypothesis and has proper statistical properties.

$$\begin{aligned} \text{Log(OPC)} = & 4.6130 + 0.2531 * \text{Log(CREW)} + 0.2743 * \text{Log(GRT)} \\ & (6.31) \quad (3.34) \quad (3.46) \\ & + 1.1134 * \text{Log(DAS)} \\ & (8.79) \end{aligned}$$

n=69, adj R-sq = 0.58, D-W = 1.97, t-value in parentheses.

(c). Consumer surplus

Consumer surplus (CS) measures the area below the demand curve and above the equilibrium price. For simplicity, consumer surplus is estimated here by approximating the demand curve between the intercept and the estimated price with a linear line as shown below. Although this method may overestimate consumer surplus slightly, it does not affect the ranking of alternatives in terms of highest consumer benefits or net economic benefits.

$$CS_t = (PINT * DLN_t - PEX_t * DLN_t) / 2$$

$$PVCS = \sum_{t=2000}^{t=2008} (CS_t / (1 + r)^t)$$

Where:  $r$  = Discount rate and assumed to be 7%.

$CS_t$  = Consumer surplus at year “t” in 1997 dollars.

$PVCS$  = Present value of the consumer surplus in 1997 dollars.

$PINT$  = Price intercept i.e., estimated price when domestic landings are zero.

$DLN_t$  = Sea scallop landings for each policy option at year “t”.

$PEX_t$  = Price of scallops at the ex-vessel level corresponding to landings for each policy option at year “t” in 1997 dollars.

(d). Producer surplus

The producer surplus (PS) is defined as the area above the supply curve and the below the price line of the corresponding firm and industry (Just, Hueth & Schmitz 1982). The supply curve in the short-run coincides with the short-run MC above the minimum average variable cost (for a competitive industry). This area between price and the supply curve can then be approximated by various methods depending on the shapes of the MC and AVC cost curves. The economic analysis presented in this section used the most straightforward approximation and estimated PS as the excess of total revenue (TR) over the total variable costs (TVC). It was assumed that the number of vessels and the fixed inputs stay constant over the time period of analysis. In other words, the fixed costs were not deducted from the producer surplus since the producer surplus is equal to profits plus the rent to the fixed inputs. Here fixed costs include various costs associated with a vessel such as depreciation, interest, insurance, half of the repair, office expenses and so on. It is assumed that these costs will not change from one policy option to another.

$$PS_t = PEX_t * DLN_t - \sum_{n=1}^m OPC_n$$

$$PVPS = \sum_{t=2000}^{t=2008} (PS_t / (1 + r)^t)$$

Where:  $n=(1, \dots, m)$ .

$m$  = number of vessels.

$r$  = Discount rate and assumed to be 7%.

$OPC_n$  = Operating costs of the vessel “n” at year t.

$PS_t$  = Producer surplus at year “t” in 1997 dollars.

$PVPS$  = Present value of the producer surplus in 1997 dollars.

$DLN_t$  = Sea scallop landings for each policy option at year “t”.

$PEX_t$  = Price of scallops at the ex-vessel level corresponding to landings for each policy option at year “t” in 1997 dollars.

### Evaluation of Area Rotation Management Policy

Three tasks are required in the evaluation of sea scallop area rotation system. First, management policy options must be constructed in open/closure by area and time. Second, a biological model must be available and initial values should be set for simulating the policy options. Third, an economic model should also be available for evaluating the policy options in economic terms.

#### Management policy options

In the real world, the fishery management decision process is a political process conducted in public and involves explicit, implicit, quantifiable and un-quantifiable factors. The process is very complex and hard to understand fully, making the adoption of an optimal control model impractical at best in assisting the decision process. Other analytical methods should be developed as alternative approaches.

Our model presented above is developed as an alternative approach. For the purposes of demonstration, only two policy options are designed and evaluated in this paper. It should be noted, however, that the model is capable of evaluating many similar options. Furthermore, the political process in deciding policy options involves various interest groups including scientists, industry participants, conservation and recreational interests, the public and fishery managers at the federal and state levels. Some feasible area rotation systems that result from the political process, therefore, might be optimal or near optimal concerning all the parties involved. The two options chosen here for the demonstration purposes are:

Option 1: The Sea scallop Fishery Management Plan Amendment Seven (A7) - Status Quo.

This option assumes the continuation of the A7 fishing mortality schedule and area access policy, and includes the following assumptions:

- (1) 120 days at sea per vessel,
- (2) Georges Bank Closed Area II Southeast is opened to scallop fishing in 2000,

- (3) Georges Bank closed area II North remain closed in 2001,
- (4) Mid-Atlantic closed areas are open to scalloping in 2001,
- (5) effort removed from one area is assumed to shift to other areas, and
- (6) every area will be opened to scalloping starting year 2001 at the uniform fishing mortality rate corresponding to that year.

The detailed area closure/open schemes under the A7 option are presented in Table 3. For example, the Southeast portion of Georges Bank under the A7 option was fished at the fishing mortality of 0.5 in 1999, and will open for scalloping every year from 2000 to 2008. The mortality rate for the area will be 0.4 in 2000 and reduced to 0.15 in 2007 and rise to a higher rate of 0.20 in 2008.

#### Option 2: Area Rotation management System (RS).

Like the A7 option above, the RS option includes items (1) through (5), implying no difference in area open/closure management scheme in 2000 (the first year of simulation). However, unlike the A7 option that opens all the areas to scalloping starting year 2001, the RS option varies open/closure by areas at different fishing mortality rates each year. The detailed area closure/open scheme under the RS option is also presented in Table 3. For example, unlike that under the A7 option, the Southeast portion of the Georges Bank is closed for most years except the years 2000, 2004, and 2007 during which it will be opened at the fishing mortality rates of 0.4, 0.60 and 0.80 respectively under the RS option.

In constructing the above options, several factors were considered. First, both options should meet the FMP objective by 2008. Second, the end year (i.e., 2008) should have about the same level of the fishing mortality rate between two options. Third, the end year should have approximately the same level of spawning biomass for the

two options. Fourth, the opening of an area under the RS option should consider the sizes and growth of scallops in the area. An area with larger scallops and smaller growth is preferred for opening to fishing compared to an area with smaller scallops and higher growth.

#### Initial value and model simulation.

Initial values must be set for the biological model in Section 2 above to begin the simulation of policy options.

The initial values for this analysis are set to the 1999 actual values of the fishery except that a few values are projected as explained below. The simulation generates measures of various biological variables as a policy outcome for a period from 2000 to 2008. The year of 2008 is the year by which the sea scallop management plan is required to meet a specific goal for fishing mortality rate and spawning biomass.

#### (a) Initial Conditions

Initial conditions for the population vector  $P(i,t)$  were generally estimated based on the mean catch per unit effort in each size class and area observed during the 1999 NMFS research vessel sea scallop survey. However, only one tow (which is zero catch) was performed in stratum 49, in the South channel region. In order to estimate the density in the stratum, we used the 1998 survey density in this stratum, projected forward for one year. Also the biomass estimate for the Nantucket Light Ship area was considerably higher than several other estimates of biomass in this region, including the projections of the 1998 survey, the joint NMFS/industry survey, and the video survey by the Center for Marine Science and Technology, UMAS. Consequently, we initialized this area to the 1998 survey, projected forward for one year. Catches were adjusted for survey catchability, as described in SARC 23 (1996). The mean initial biomass of each area is shown in Table 4.

**Table 3: Fishing mortality rates, F(n), for area rotation system (RS) and Amendment 7 (A7) options**

**A. Georges Bank**

Southeast Portion		Closed Area 1		Closed Area2- North		Closed Area2- South		Northeast Portion		Nantucket Lightship Area-99		South Channel		Composite	
A7	RS	A7	RS	A7	RS	A7	RS	A7	RS	A7	RS	A7	RS	A7	RS
0.50	0.50	-	-	-	-	0.40	0.40	0.50	0.50	-	-	0.50	0.50	0.21	0.21
0.40	0.40	0.20	0.20	-	-	0.20	0.20	0.40	0.40	0.20	0.20	0.40	0.40	0.24	0.24
0.28	-	0.28	0.33	-	-	0.28	-	0.28	-	0.28	0.33	0.28	0.20	0.24	0.15
0.24	-	0.24	0.37	-	-	0.24	-	0.24	-	0.24	0.37	0.24	0.20	0.20	0.14
0.22	0.60	0.22	-	-	-	0.22	0.60	0.22	-	0.22	-	0.22	-	0.18	0.13
0.15	-	0.15	0.60	-	-	0.15	-	0.15	0.60	0.15	-	0.15	-	0.12	0.12
0.15	-	0.15	-	-	-	0.15	-	0.15	-	0.15	0.33	0.15	0.33	0.12	0.14
0.15	-	0.15	-	-	-	0.15	-	0.15	-	0.15	0.40	0.15	0.40	0.12	0.14
0.15	0.80	0.15	-	-	-	0.15	0.80	0.15	-	0.15	-	0.15	-	0.12	0.15
0.20	-	0.20	0.80	-	-	0.20	-	0.20	0.80	0.20	-	0.20	-	0.16	0.16
0.24	0.23	0.17	0.23	-	-	0.21	0.20	0.24	0.23	0.17	0.16	0.24	0.20	0.17	0.16

**B. Mid Atlantic**

Time	Delmarva		Hudson Canyon		New York Bight		Virginia Beach		Composite	
	A7	RS	A7	RS	A7	RS	A7	RS	A7	RS
1999	0.50	0.50	-	-	0.50	0.50	-	-	0.19	0.19
2000	0.50	0.50	-	-	0.50	0.50	-	-	0.18	0.18
2001	0.28	-	0.28	0.30	0.28	-	0.28	0.30	0.28	0.17
2002	0.24	-	0.24	0.36	0.24	-	0.24	0.36	0.24	0.16
2003	0.22	-	0.22	0.45	0.22	-	0.22	0.45	0.22	0.14
2004	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
2005	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
2006	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
2007	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
2008	0.20	0.18	0.20	0.18	0.20	0.18	0.20	0.18	0.20	0.18
Annual Average	0.25	0.19	0.15	0.20	0.25	0.19	0.15	0.20	0.19	0.17

" - " Closure

A7 (Amendment 7)

RS (Area Rotation System)

Table 4: Initial Conditions based on 1999 NMFS Survey

Region	Fishing Mortality Inputs		Survey-based Biomass & Numbers			Average Size (g meat wt)	
	Direct Landings (1/yr)	Total=Direct +Indirect (1/yr)	Total Biomass (g/tow)	Exploitable Biomass (g/tow)	Numbers (no./tow)	All Sizes (g)	Exploitable (g)
<b>Georges Bank</b>							
South Channel	0.400	0.500	1,576	1,171	194	8.1	14.7
Southeast Part	0.400	0.500	1,181	946	125	9.4	12.9
N. Edge & Peak	0.400	0.500	923	742	100	9.2	13.3
Area I	0.000	0.000	8,474	8,122	456	18.6	20.9
Area II-South	0.400	0.500	3,504	3,180	260	13.5	17.6
Area II-North	0.000	0.000	3,189	3,070	178	17.9	19.6
Nantucket Lightship-99	0.000	0.000	10,257	9,167	878	11.7	25.2
Nantucket Lightship-98	0.000	0.000	5,263	5,052	250	21.1	24.8
<b>Average</b>	<b>0.140</b>	<b>0.175</b>	<b>2,935</b>	<b>2,671</b>	<b>204</b>	<b>14.4</b>	<b>19.0</b>
<b>Mid-Atlantic</b>							
New York Bight	0.400	0.500	1,374	1,086	188	7.3	13.2
Hudson Canyon	0.000	0.000	6,559	4,243	996	6.6	10.0
Delmarva	0.400	0.500	1,563	1,163	202	7.7	11.9
Virginia Beach	0.000	0.000	5,291	5,006	376	14.1	17.3
<b>Average</b>	<b>0.170</b>	<b>0.213</b>	<b>2,397</b>	<b>1,738</b>	<b>335</b>	<b>7.1</b>	<b>11.7</b>

Region	Projected Landings: Survey Units Landings (g/tow)	Projected Discards: Survey Units Discards (g/tow)	Fecundity Index: Survey Units Eggs (no. x 10 <sup>6</sup> /2/tow)	Expanded Total Landings and Biomass (mt)		
				Landings (mt)	Population Biomass (mt)	Exploitable Biomass (mt)
<b>Georges Bank</b>						
South Channel	622.5	-	6125	1,879	4,756	3,534
Southeast Part	470.3	-	4252	1,626	4,082	3,269
N. Edge & Peak	369.2	-	3398	779	1,947	1,565
Area I	0	-	37914	-	11,695	11,209
Area II-South	1312.3	-	12503	2,748	7,338	6,659
Area II-North	0	-	14402	-	5,999	5,776
Nantucket Lightship-99	0	-	47365	-	-	-
Nantucket Lightship-98	0	-	23842	-	11,536	11,071
<b>Average</b>	<b>435.9</b>	<b>-</b>	<b>12287</b>	<b>7,032</b>	<b>47,353</b>	<b>43,084</b>
<b>Mid-Atlantic</b>						
New York Bight	477	11.2	4396	5,554	16,002	12,648
Hudson Canyon	0	0	25790	-	20,862	13,495
Delmarva	553.7	14.1	4976	1,686	4,758	3,541
Virginia Beach	0	0	20488	-	2,212	2,093
<b>Average</b>	<b>395.9</b>	<b>9.5</b>	<b>8581</b>	<b>7,246</b>	<b>43,834</b>	<b>31,777</b>

## (b) Biological simulation

The simulation is done by each of the 12 individual areas. The results of the simulation were then summarized for two general areas (Georges Bank and Mid-Atlantic resources areas) while the results can be made available for each individual area. This analysis presents three biological

variables (fishing mortality rate, catch and spawning biomass) and projections for other variables, such as meat count, are also available with requests. The results are presented in Charts 2 - 6.



(c) Economic evaluation

The economic evaluation is to assess the simulated catch streams derived from the biological model simulation from 2000 to 2008. However, the catch streams need to be adjusted down by 30% so that the catch streams will be consistent with the landing streams used in the economic model. The adjustment is necessary to take into account for unreported and/or undocumented landings, which are included in the biological modeling but excluded in economic modeling.

The economic evaluation includes the impacts of policy options on exvessel prices, fleet revenues, consumer surplus, produce surplus and net economic benefits (i.e., producer surplus plus consumer surplus). The findings are presented in Charts 6 - 10.

(d) Comparison of the two options

As designed, the fishing mortality under these two options would be achieved at about the same rate, at 0.16 for the Georges Bank scallop stock in 2008, and would fluctuate between 0.12 and 0.24 during the period from 2000 through 2008 (Chart 2). However, a different fishing mortality picture is shown for the Mid-Atlantic stock. The fishing mortality under the RS option would not only achieve a lower rate in 2008 but also fluctuate within a smaller range than under the A7 option (Chart 3).

The two options would achieve about the same level of exploitable biomass for both stocks in year 2008 (Charts 4-5). Nevertheless, the RS option is a better option since it rebuilds biomass faster exceeding the corresponding levels under the A7 option for most years (2000 - 2007) during the period.

Total landings in 2008 under the RS option would be slightly lower than that under the A7 option (77 million pounds versus 81 million pounds, Chart 6). However, the RS option would provide a more stable landings stream over the period, making economic planning easier by vessels and the industry as a whole, and thus helping the industry to gain higher economic efficiency.

Sea scallop ex-vessel prices (in the 1997 dollars) for the RS option is more stable during the same period and at a slightly higher level in 2008 than the level under the A7 option (Chart 7). Similarly, total ex-vessel revenue under the RS option would be more stable and would increase constantly during the period (2001-2008), whereas fleet revenues would fluctuate under the A7 option. Unlike the price, however, the fleet revenue in the last year, in 2008, would be slightly less under the RS option compared to the A7 option (Chart 8).

Both consumer and producer surpluses follow a similar pattern as the ex-vessel revenue: Both would be more stable under the RS option, although at a slightly lower level in 2008 than that of under the A7 option (Charts 9-10).

Based on a comparison of present value of three economic indicators, that is, the consumer surplus, producer surplus, and the net economic benefits (each discounted at the 7% rate over the period), it is shown that the RS option would be preferred because of the higher present values compared to the A7 option. The present value of consumer surplus under the RS option would be about \$21 million higher, and the present value of producer surplus would be about \$24 million higher than the corresponding levels under the A7 option. As a result, the present value of the net economic benefits (the sum of present values of the consumer surplus and the producer surplus) for the RS option would exceed the net benefits for the A7 option by about \$44 million.

## Summary

In this paper, the U.S. sea scallop fishery and management were briefly described and followed by a presentation of a bio-economic model which was developed to evaluate area rotation management options for the scallop fishery. As a demonstration of model application, two potential management options for the fishery were constructed for the evaluation using the bio-economic model.

The biological model consists of two components including biology and economics. The biological model is a sized structure model for 11 resource areas while the economic model is an econometric model including ex-vessel price and operating costs equations. The biological model was used to simulate policy options and measured biological indicators e.g., spawning biomass and catch streams over a period from 2000 through 2008. The economic model assessed the policy options by evaluating the catch streams derived from the biological simulation and measured the policy impact on scallop prices, revenues, consumer surplus, producer surplus and net economic benefit.

Of the two options evaluated, one is the status quo policy (Scallop Management Plan Amendment 7) that allows fishing in almost all areas of the Georges Bank and the Mid-Atlantic, and the other is an area rotation management system. Our evaluation indicates that it is possible to structure some area rotation management systems that could be superior to the status quo policy. Even though our model was used to demonstrate its use of an evaluation of two options, this bio-economic model is capable of evaluating many similar options.

Chart 2: Fishing Mortality  $F(n)$  for Georges Bank for the rotational and Amendment 7 options

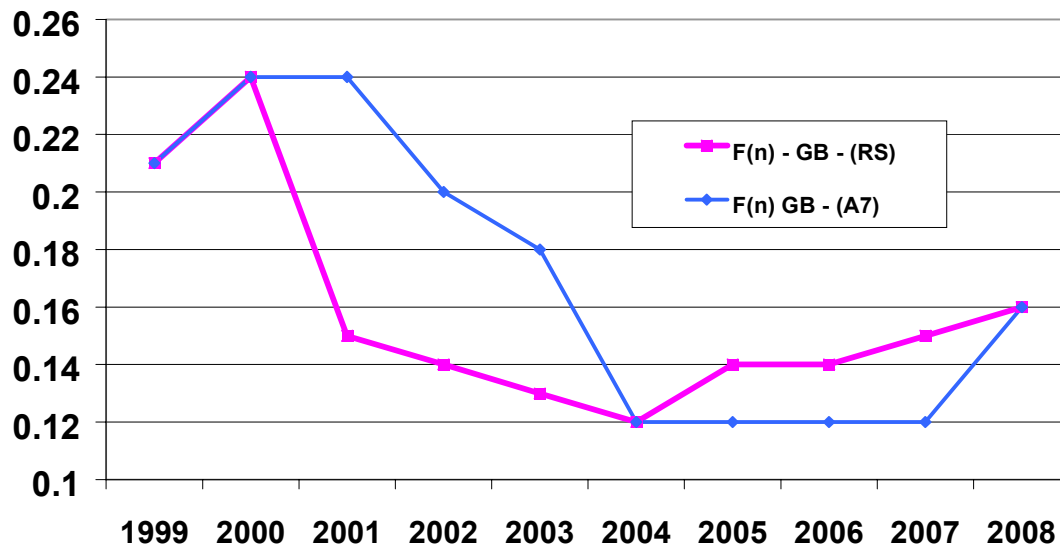
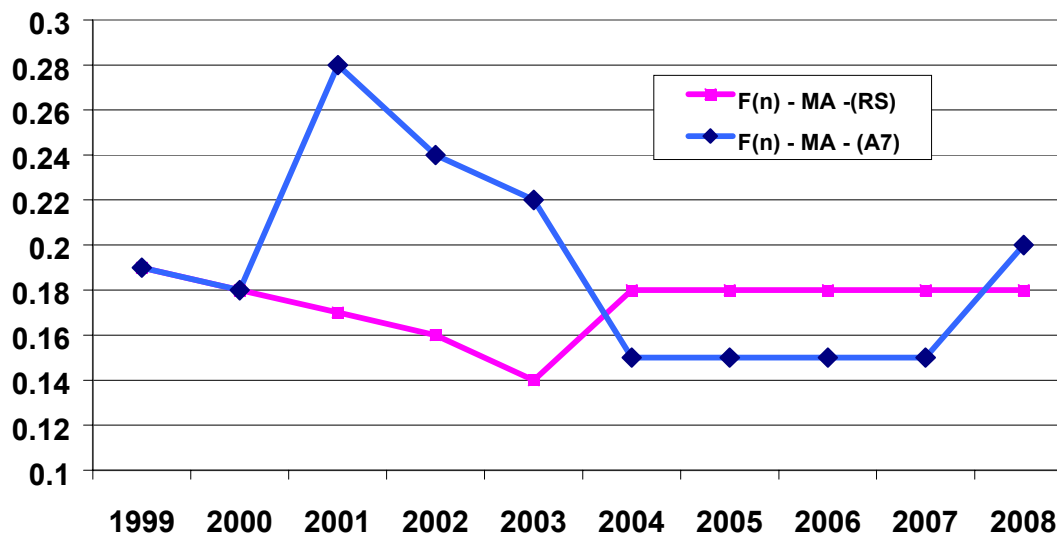
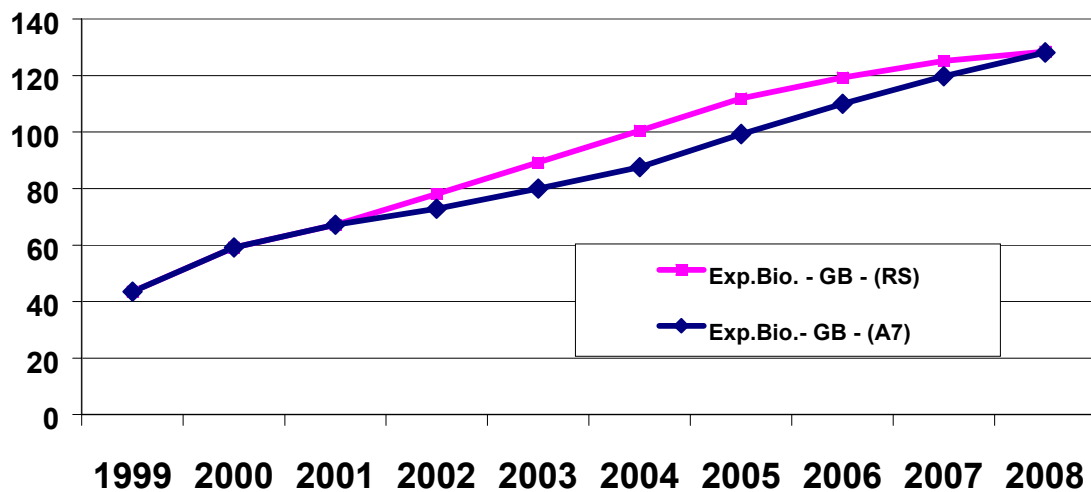


Chart 3: Fishing Mortality  $F(n)$  for Mid-Atlantic for the rotational and Amendment 7 options



**Chart 4: Exploitable biomass (thousand metric tons) rotational and Amendment 7 options for Georges Bank**



**Chart 5: Exploitable biomass (thousand metric tons) rotational and Amendment 7 options for Mid- Atlantic**

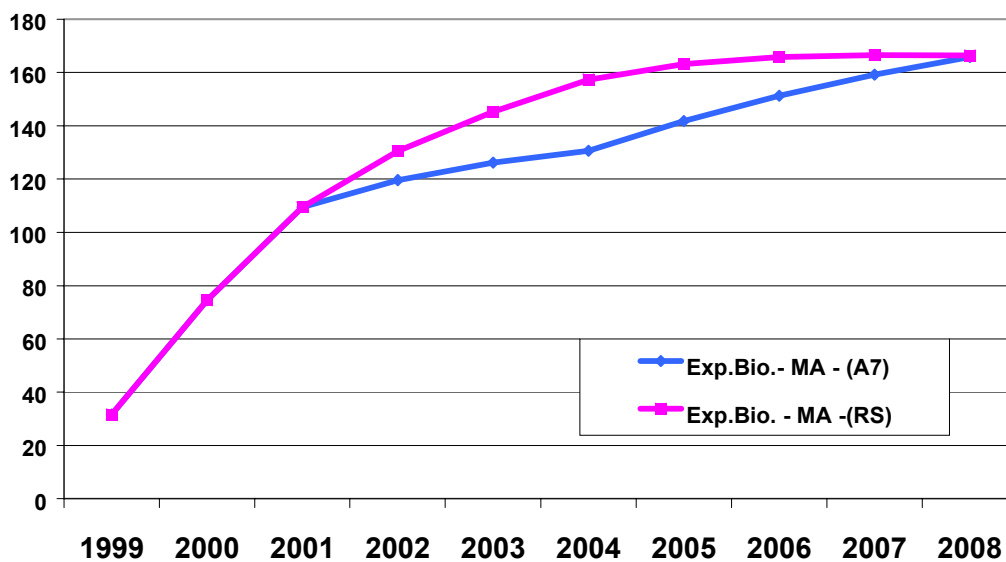


Chart 6: Total scallop landings in million pounds (all areas)

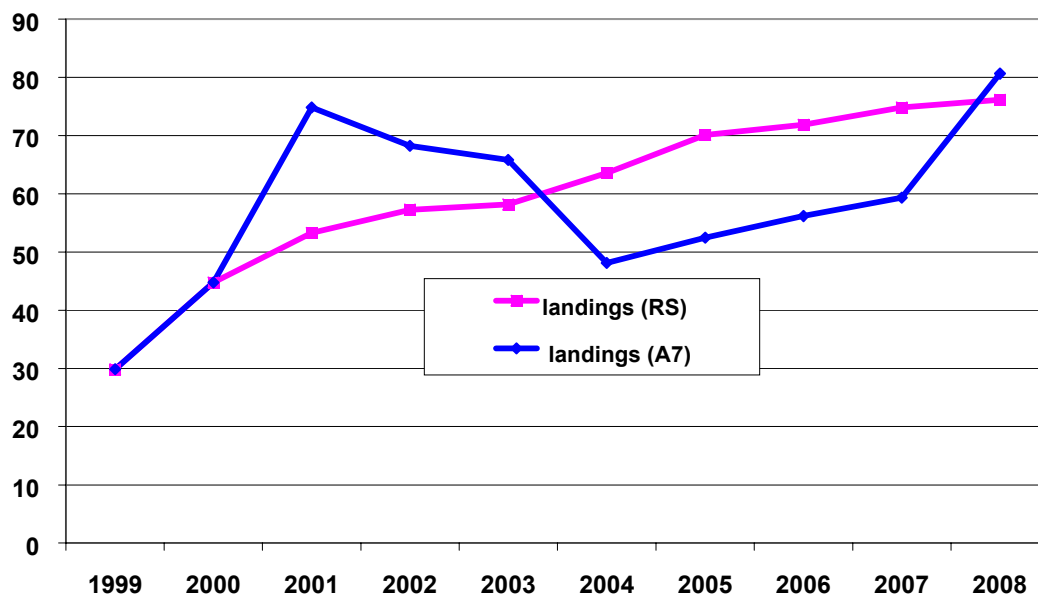


Chart 7: Ex-Vessel Price (dollars per pound in 1997 prices)

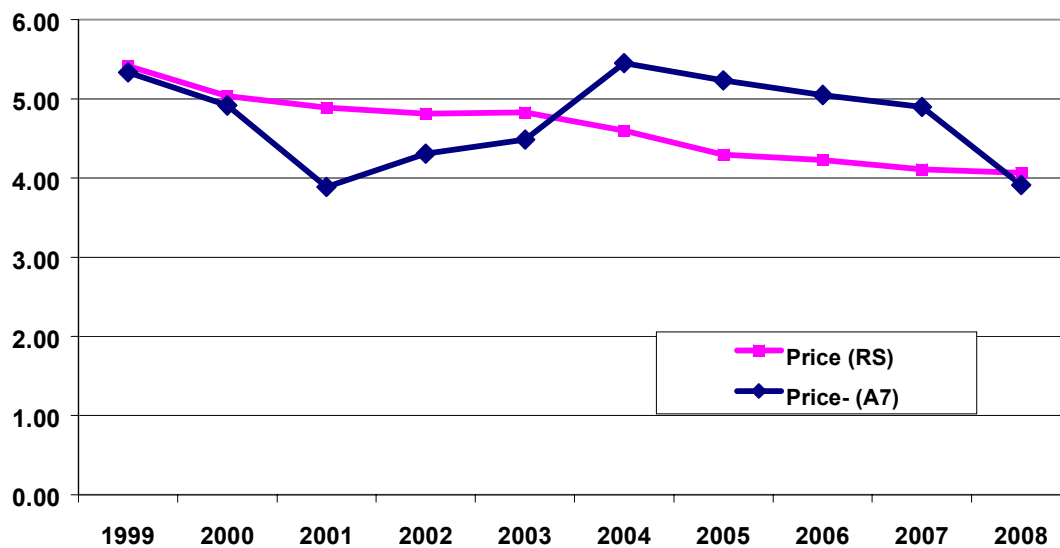


Chart 8: Total Revenue (1997 million dollars)

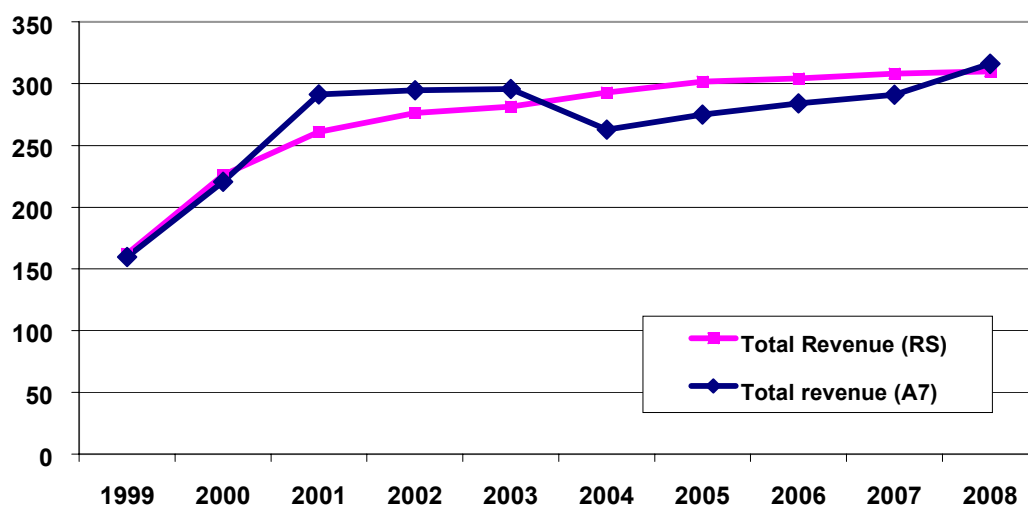
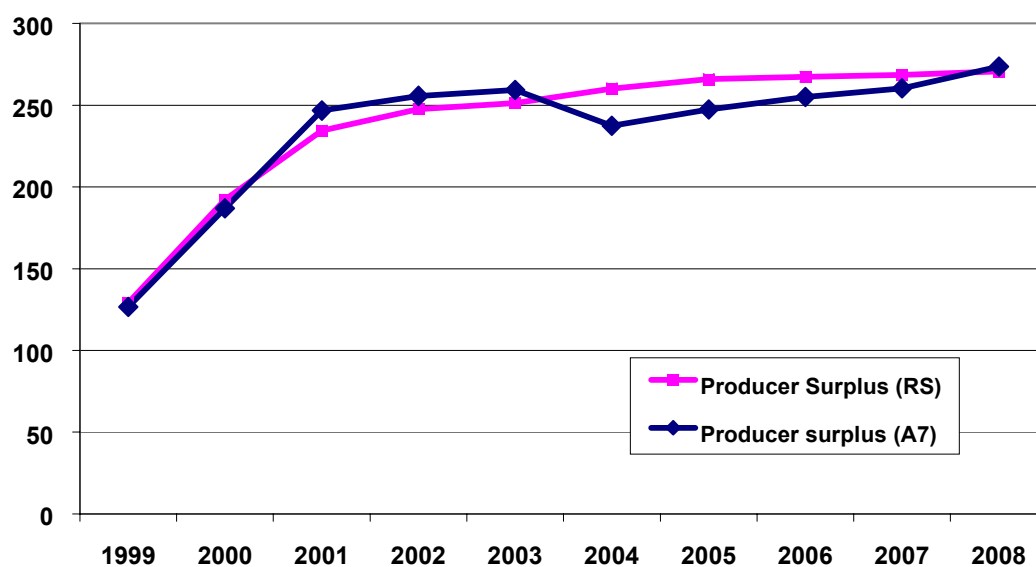


Chart 9: Producer Surplus (in 1997 million dollars)



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\* Demet Haksver is economist at New England Fishery Management Council. Deborah Hart and Stanley Wang are operation research analyst and economist, respectively, at National Marine Fisheries Service. We would like to acknowledge Renee Olsen and Kurt Wilhelm for their valuable assistance in the preparation of tables and charts for this paper. Opinions expressed in this paper do not reflect the policies of their employers.

<sup>1</sup> An economic analysis of the policy alternative options is available in Wang et al (1986).